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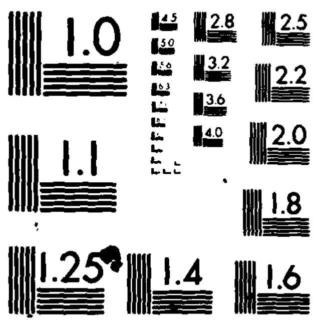
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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

In this project, the basic research on inclusions and its application to inhomogeneities of materials has been sought. Interactions among precipitating particles, cracks, voids, and plastic domains have been investigated to obtain overall mechanical properties of materials.

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INTERACTION AMONG INHOMOGENEITIES

FINAL REPORT

T. Mura

December 1980

U.S. Army Research Office

DAAG29-77-G-0042

Northwestern University

Evanston, Illinois 60201

THE FINDINGS IN THIS REPORT ARE NOT TO BE CONSTRUED AS AN OFFICIAL DEPARTMENT OF THE ARMY POSITION, UNLESS SO DESIGNATED BY OTHER AUTHORIZED DOCUMENTS.

A. Statement of Problem Studied and Summary of Research Results

In this project defects are defined as inclusions and inhomogeneities. When the uniformity of an elastic medium is disturbed by a region within it which has changed its form by some reasons, for instance, precipitation of a new phase, thermal expansion, martensite transformation, twin form, and plastic slip, the region is called an inclusion. The character of the inclusion is that it causes an internal stress field (self equilibrating stress field).

When a material has a region which has elastic moduli differing from those of the remainder, the region is called an inhomogeneity. The inhomogeneity itself does not necessarily cause an internal stress field, but it always disturbs other stress fields. Voids, cracks, impurities are examples of the inhomogeneity. Some defects are inclusions and at the same time inhomogeneities, as seen in precipitates and impurities. The remaining material outside of the defects is called a matrix. Structural elements of a composite material can be viewed as inhomogeneities if the elements are dilutely dispersed in the matrix. Line imperfections such as dislocations and disclinations, according to the present classification, are inclusions where the slip plane is the region which takes a shape-change described by Dirac's delta function.

The failure of various equipments due to defects in solid materials is mostly caused by the interaction between defects and applied stresses. Although chemical and physical effects other than mechanical effects are also involved in the failure, as seen in corrosion, the primary objective of this project is to consider the elastic interaction of the defects in anisotropic materials subjected to contain stress fields.

The study of the elastic interaction of defects is not only important for the failure of materials, but it is also useful for controlling the phenomena of plastic deformation, including creep, creep-rupture, static and cyclic fatigue, strain-hardening, dynamic recovery, age or precipitation hardening, spinodal and eutectoid decomposition, and recovery and recrystallization. The change in the gross elastic moduli of a material when a dilute dispersion of defects is introduced into it, is also a subject which is discussed in connection with the elastic interaction of defects.

Although extensive studies on the elastic interaction of defects have been made for isotropic elastic materials, no progress has been made in anisotropic elasticity. Most materials are anisotropic as seen in single crystals, ceramics, reinforced materials, rolled polycrystals, and composite materials. Even when the matrix of a material is isotropic, a defect is anisotropic, or vice versa. Some materials (i.e. polycrystals) have gross (macroscopic) isotropic elastic moduli but manifest local (microscopic) anisotropy. On the other hand, some composite materials have gross anisotropic characteristics, but are locally isotropic.

The elastic interaction of defects depends on the geometry involved, namely, the shape and the distribution of the defects in the matrix. In this project the shape of the defects is limited to an ellipsoid, which is sufficiently general for practical purposes. Spherical, penny, and needle (rod) shapes are special cases of the ellipsoid. The ellipsoidal shape of a defect has a great advantage in that the stress field inside the defect becomes uniform.

1. The basic research has been done about the elastic field outside an ellipsoidal inclusion. This is an extension of Eshelby's result in the sense that no particular restrictions are imposed to eigenstrain distributions throughout the inclusion and to the anisotropy of elastic media for matrices.

When eigenstrains are of a polynomial form, the general formula for the elastic field is further developed to a special form.

We have found a very special inclusion which does not introduce any stress field. It is called an impotent inclusion. Such an inclusion exists when an eigenstrain is a gradient of a function which vanishes at the boundary of the inclusion.

Another significant result has been obtained in the basic research for the elastic field of a periodic distribution of inclusions. We have found that the sum of the solutions for individual inclusions is not convergent. A new rule for the summation is proposed.

2. Various application problems of inclusions are proposed and solved.

Creation and relaxation of the back stress in a dispersion hardened alloy are evaluated in terms of behavior of Orowan loops around an inclusion. Phenomena of annealing and creep of alloys are well explained by this model.

Some alloys have a special distribution of precipitates. For instance, the arrangement of nitrogen atoms in α" precipitate, $Fe_{16}N_2$, observed as an intermediate phase in supersaturated iron-nitrogen alloys is a body centered cubic. This can be predicted as the strain energy minimum state compared with other arrangements (face centered and simple cubic).

Interesting interaction problem is found in the area of fracture mechanics. We have evaluated the weakening of an elastic solids by a periodic array of penny-shaped cracks.

In connection with Energy Problem, we have investigated the growth of planar cracks induced by hydraulic fracturing. This is an application of the inclusion theory to geothermal energy extraction problem. Our research on the elastic field in a half space due to ellipsoidal inclusions with uniform dilatation and thermal stresses around an elastic ribbonlike inclusion with good thermal conductivity are related to this geothermal energy extraction problem.

A new inclusion application is found in the area of materials science. We have considered the surface diffusion around the inclusion. This diffusional relaxation gives a new aspect of internal friction and creep of alloys caused by second phase particles. A theoretical prediction of particle size dependency of this relaxation is proved by the experiments carried out at the Tokyo Institute of Technology.

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